Claims

What is claimed is:

[c1] A method of simulating subsea mudlift drilling well control operations using a computer system, the method comprising:

simulating a drilling circulation system, the simulated circulation system comprising at least one blowout preventer, at least one isolation line, at least one surface pump, a subsea mudlift pump, drill pipe, drilling fluid, and a wellbore;

simulating drilling the wellbore at a selected rate of penetration, the simulating drilling a wellbore comprising simulating drilling selected earth formations;

simulating a kick at a selected depth in the wellbore proximate a selected earth formation, the kick simulated as a two-phase mixture comprising drilling fluid and a formation fluid;

simulating controlling the kick, the simulating controlling the kick comprising:

simulating shutting the at least one blowout preventer;

simulating opening the at least one isolation line;

simulating circulating a formation fluid influx out of a well while an inlet pressure of a subsea mudlift pump is adjusted to maintain a substantially constant drill pipe initial circulating pressure;

simulating pumping drilling fluid with a kill mud weight from the surface into the well;

simulating reducing the drill pipe pressure according to a preselected drill pipe pressure decline schedule until the kill mud weight drilling fluid reaches a bottom of the well;

simulating maintaining the drill pipe pressure at a final circulating pressure after the kill mud weight drilling fluid reaches the

bottom of the well by adjusting the inlet pressure of the subsea mudlift pump; and

simulating circulating kill mud weight drilling fluid from the bottom of the well to the surface at the final circulating pressure;

displaying wellbore parameters via a graphical user interface operatively coupled to the computer system, the wellbore parameters comprising a drill pipe pressure, a subsea mudlift pump inlet pressure, a surface pump flow rate, a subsea mudlift pump flow rate, a formation pressure, a blowout preventer status, an isolation line status, a drilling fluid density, and a kill mud weight drilling fluid density; and

repeating the simulating drilling the wellbore after the kick has been controlled.

[c2] The method of claim 1, further comprising selecting an operating mode of the subsea mudlift pump.

[c3] The method of claim 1, further comprising processing well data stored in a memory operatively coupled to the computer system, the well data comprising formation pressures, a wellbore temperature gradient, a formation temperature gradient, wellbore geometry, drillstring geometry, and drilled depth.

[c4] The method of claim 1, further comprising:

determining a U-tube flow rate during the simulating if the drillstring is not full of drilling fluid to enable determining the subsea mudlift pump inlet pressure.

[c5] The method of claim 3, wherein the well data comprises real-time well data received from sensors and well equipment disposed proximate the wellbore and operatively coupled to the computer system and to the memory.

[c6] The method of claim 1, wherein the simulating drilling a wellbore comprises simulating drilling at half of a selected rate of penetration before reaching a

selected kick depth and simulating drilling at the selected rate of penetration after reaching the selected kick depth.

[c7] The method of claim 1, wherein the simulating a drilling fluid circulation system comprises simulating a drill string valve, the drill string valve simulated as a choke that induces pressure losses in the circulation system.

[c8] The method of claim 1, wherein the simulating a kick comprises simulating a total flow comprising drilling fluid and formation fluid, wherein the kick is simulated as bubble flow if a gas fraction of the total flow is less than 25%, slug flow if the gas fraction is greater than 55% and less than 75% of the total flow, and annular flow if the gas fraction is greater than 90% of the total flow.

[c9] The method of claim 1, wherein the controlling a kick comprises:

determining a location of a top of the kick;

calculating a kick pressure in each of at least two layers defined within the two-phase mixture;

calculating hydrostatic pressure and acceleration losses due to gas expansion from the top of the kick to an inlet of a subsea mudlift pump using the calculated kick pressures;

calculating a subsea pump flow rate required to maintain a substantially constant subsea mudlift pump inlet pressure;

calculating a surface pump pressure and a standpipe pressure; and

calculating pressures at selected locations in the drilling fluid circulation system, wherein the calculated pressures may be used in the simulating circulating the formation fluid influx out of the well.

[c10] The method of claim 1, wherein the controlling a kick comprises:

determining a location of a top of the kick;

calculating a kick pressure in each of at least two layers defined in the two-phase mixture; and

adjusting the simulation ratio to five times faster than real-time if the top of the kick passes a midpoint of a return line.

[c11] The method of claim 10, further comprising simulating circulating one mixture layer at a time through the subsea mudlift pump if the kick is entirely below the mud line.

[c12] The method of claim 10, further comprising calculating kick pressures in the wellbore and in the return line if at least part of the kick is above the mud line and at least part of the kick is below the mud line.

[c13] The method of claim 10, further comprising calculating kick pressures in the return line if the kick is completely above the mud line.

[c14] The method of claim 1, wherein the simulating controlling the kick comprises:

determining a location of a top of the kick;

calculating a current subsea mudlift pump flow rate and inlet pressure;

calculating a pressure and volume of the kick; and

calculating pressures at selected locations in the drilling fluid circulation system, wherein the calculated pressures may be used in the simulating circulating the formation fluid influx out of the well.

[c15] The method of claim 14, further comprising determining a gas outflow rate proximate the earth's surface when the kick reaches the surface.

[c16] The method of claim 14, further comprising determining an effective gas outflow rate in the return line using a determined gas kick expansion rate over a selected time interval.

[c17] The method of claim 14, wherein the determining a location of the top of the kick comprises determining a location of a top of the two-phase mixture.

[c18] The method of claim 1, wherein the simulating the kick comprises:

calculating a total kick influx for a selected time duration after a selected formation has been drilled;

calculating an effective two-phase gas volume fraction of a total volume of circulating fluid, the total volume comprising the two-phase mixture and the drilling fluid;

calculating an average pressure in the two-phase mixture; and

calculating pressures at selected locations in the circulation system, wherein the calculated pressures may be used in the simulating controlling the kick.

[c19] The method of claim 18, wherein the two-phase mixture is modeled as a slug having an effective gas fraction.

[c20] The method of claim 18, further comprising determining a change in a drilling fluid level in the circulation system after a kick has entered the wellbore, the change in drilling fluid level determined as:

$$\Delta h = -\frac{\Delta BHP}{0.052 \cdot \rho}$$

where Δh is the change in drilling fluid level, ΔBHP is a change in bottom hole pressure caused by the kick, and ρ is a drilling fluid density.

[c21] The method of claim 1, wherein the simulating a kick comprises:

selecting a location of a bottom of the kick in the wellbore;

determining a first two-phase friction pressure loss above the bottom location of the kick;

determining a kick height in the wellbore;

determining a location of a top of the kick;

determining a second two-phase friction pressure loss above the top of the kick; and

determining a total friction pressure loss for the kick as a difference between the first and second determined two-phase friction pressure losses.

[c22] The method of claim 1, wherein the two-phase mixture comprises at least two discrete layers, each layer comprising a drilling fluid fraction and a formation fluid fraction.

[c23] The method of claim 22, wherein each mixture layer comprises an effective gas volume fraction.

[c24] The method of claim 22, wherein drilling fluid can move from a first mixture layer to an adjacent mixture layer disposed above the first mixture layer if a gas volume fraction of the first mixture layer is higher than a selected level.

[c25] The method of claim 24, wherein the selected level is 85% gas by volume.

[c26] The method of claim 22, wherein drilling fluid can move from a top mixture layer to an adjacent mixture layer disposed below the top mixture layer if a gas volume fraction of the top mixture layer is greater than 45%.

[c27] The method of claim 22, wherein a gas rise velocity proximate a top layer defining the top of the kick is calculated using a gas fraction of the top layer.

[c28] The method of claim 27, wherein gas rise velocities of other layers in the two-phase mixture are determined from an effective mixture volume of each layer.

[c29] A method of performing real-time well control operations, the method comprising:

simulating a drilling circulation system, the simulated circulation system comprising at least one blowout preventer, at least one isolation line, at

least one surface pump, a subsea mudlift pump, drill pipe, drilling fluid, and a wellbore;

simulating drilling the wellbore at a selected rate of penetration, the simulating drilling a wellbore comprising simulating drilling selected earth formations;

detecting a kick in an operating well, the computer system operatively coupled to sensors disposed in the operating well, the sensors adapted to detect the kick and to communicate a kick depth and a kick volume to the computer system;

simulating the kick at the kick depth in the wellbore, the kick simulated as a two-phase mixture comprising drilling fluid and a formation fluid;

simulating controlling the kick using the communicated kick depth and kick volume, the simulating controlling the kick comprising:

simulating shutting the at least one blowout preventer;

simulating opening the at least one isolation line;

simulating circulating a formation fluid influx out of a well while an inlet pressure of a subsea mudlift pump is adjusted to maintain a substantially constant drill pipe initial circulating pressure;

simulating pumping drilling fluid with a kill mud weight from the surface into the well;

simulating reducing the drill pipe pressure according to a preselected drill pipe pressure decline schedule until the kill mud weight drilling fluid reaches a bottom of the well;

simulating maintaining the drill pipe pressure at a final circulating pressure after the kill mud weight drilling fluid reaches the bottom of the well by adjusting the inlet pressure of the subsea mudlift pump; and

simulating circulating kill mud weight drilling fluid from the bottom of the well to the surface at the final circulating pressure;

displaying wellbore parameters via a graphical user interface operatively coupled to the computer system, the wellbore parameters comprising a drill pipe pressure, a subsea mudlift pump inlet pressure, a surface pump flow rate, a subsea mudlift pump flow rate, a formation pressure, a blowout preventer status, an isolation line status, a drilling fluid density, and a kill mud weight drilling fluid density; and

using the displayed parameters to operate the drilling circulation system.

[c30] A method of simulating subsea mudlift drilling well control operations using a computer system, the method comprising:

simulating a drilling circulation system, the simulated circulation system comprising at least one blowout preventer, at least one isolation line, at least one surface pump, a subsea mudlift pump, drill pipe, drilling fluid, and a wellbore;

simulating drilling the wellbore at a selected rate of penetration, the simulating drilling a wellbore comprising simulating drilling selected earth formations;

simulating a kick at a selected depth in the wellbore proximate a selected earth formation, the kick simulated as a two-phase mixture comprising drilling fluid and a formation fluid;

simulating controlling the kick, the simulating controlling the kick comprising:

simulating shutting the at least one blowout preventer;

simulating opening the at least one isolation line;

simulating circulating a formation fluid influx out of a well while an inlet pressure of a subsea mudlift pump is adjusted to maintain a substantially constant drill pipe initial circulating pressure;

simulating pumping drilling fluid with a kill mud weight from the surface into the well;

simulating holding the inlet pressure of the subsea mudlift pump substantially constant until the kill mud weight drilling fluid reaches a bottom of the well;

simulating adjusting the inlet pressure of the subsea mudlift pump to maintain the drill pipe pressure at a final circulating pressure after the kill mud weight drilling fluid reaches the bottom of the well; and

simulating circulating kill mud weight drilling fluid from the bottom of the well to the surface at the final circulating pressure;

displaying wellbore parameters via a graphical user interface operatively coupled to the computer system, the wellbore parameters comprising a drill pipe pressure, a subsea mudlift pump inlet pressure, a surface pump flow rate, a subsea mudlift pump flow rate, a formation pressure, a blowout preventer status, an isolation line status, a drilling fluid density, and a kill mud weight drilling fluid density; and

repeating the simulating drilling the wellbore after the kick has been controlled.

[c31] A method of performing real-time well control operations, the method comprising:

simulating a drilling circulation system, the simulated circulation system comprising at least one blowout preventer, at least one isolation line, at least one surface pump, a subsea mudlift pump, drill pipe, drilling fluid, and a wellbore;

simulating drilling the wellbore at a selected rate of penetration, the simulating drilling a wellbore comprising simulating drilling selected earth formations;

detecting a kick in an operating well, the computer system operatively coupled to sensors disposed in the operating well, the sensors adapted to detect the

kick and to communicate a kick depth and a kick volume to the computer system;

simulating the kick at the kick depth in the wellbore, the kick simulated as a two-phase mixture comprising drilling fluid and a formation fluid;

simulating controlling the kick using the communicated kick depth and kick volume, the simulating controlling the kick comprising:

simulating shutting the at least one blowout preventer;

simulating opening the at least one isolation line;

simulating circulating a formation fluid influx out of a well while an inlet pressure of a subsea mudlift pump is adjusted to maintain a substantially constant drill pipe initial circulating pressure;

simulating pumping drilling fluid with a kill mud weight from the surface into the well;

simulating holding the inlet pressure of the subsea mudlift pump substantially constant until the kill mud weight drilling fluid reaches a bottom of the well;

simulating adjusting the inlet pressure of the subsea mudlift pump to maintain the drill pipe pressure at a final circulating pressure after the kill mud weight drilling fluid reaches the bottom of the well; and

simulating circulating kill mud weight drilling fluid from the bottom of the well to the surface at the final circulating pressure;

displaying wellbore parameters via a graphical user interface operatively coupled to the computer system, the wellbore parameters comprising a drill pipe pressure, a subsea mudlift pump inlet pressure, a surface pump flow rate, a subsea mudlift pump flow rate, a formation pressure, a blowout preventer

status, an isolation line status, a drilling fluid density, and a kill mud weight drilling fluid density; and

using the displayed parameters to operate the drilling circulation system.